

CONSTITUENT GLUONS FROM QCD

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The notion of constituent gluon is introduced as a gluon propagating in the vacuum background field. The Hamiltonian approach for a system containing such gluon and a $q\bar{q}g$ pair is formulated, and the masses of lowest $q\bar{q}g$ hybrids are estimated.

In the QCD-motivated constituent models not only quarks but also gluons should be confined, so that the states containing constituent glue should exist. The data on mesonic spectra and decays in the mass region 1.5-2.0 GeV indicate at the existence of "extra" states, or the states with properties incompatible with properties of ordinary $q\bar{q}$ mesons. It seems reasonable to study various theoretical models to find out if the gluonic hadrons are admissible in their framework, and if the predictions have something to do with the experimental data.

Here the studies of hybrid mesonic excitations are presented in the framework of Vacuum Background Correlator method [1]. The constituent gluon is introduced starting from the perturbation theory expansion in nonperturbative QCD vacuum [2]. The gluonic field A_μ is split into the background part B_μ and the perturbation a_μ over background, and, for example, one-gluon hybrid may be represented as

$$\Psi(x_q, x_{\bar{q}}, x_g) = \psi(x_{\bar{q}})\Phi(x_{\bar{q}}x_g)a(x_g)\Phi(x_gx_{\bar{q}})\psi(x_q) \quad (1)$$

where parallel transporter Φ contains only background field.

The Green function of a $q\bar{q}g$ state can be written using the Feynman-Schwinger representation as a path integral over paths of quarks and gluon: (the details may be found in [3]):

$$G(x_q x_{\bar{q}} x_g; y_q y_{\bar{q}} y_g) = \quad (2)$$

$$\int_0^\infty ds \int_0^\infty d\bar{s} \int_0^\infty dS \int Dz D\bar{z} DZ \exp(-\mathcal{K}_q - \mathcal{K}_{\bar{q}} - \mathcal{K}_g) < \mathcal{W} >_B$$

where

$$\mathcal{K}_q = m_q^2 s + \frac{1}{4} \int_0^s \dot{z}^2(\tau) d\tau, \quad \mathcal{K}_{\bar{q}} = m_{\bar{q}}^2 \bar{s} + \frac{1}{4} \int_0^{\bar{s}} \dot{\bar{z}}^2(\tau) d\tau, \quad \mathcal{K}_g = \frac{1}{4} \int_0^\xi \dot{Z}^2(\tau) d\tau,$$

and the Wilson loop operation \mathcal{W} in (2) may be written as

$$\mathcal{W} = \frac{1}{2} W_1 W_2 - \frac{1}{2N_c} W, \quad (3)$$

where W_1, W_2 and W are the Wilson loops (in the fundamental representation) along the closed contours formed by the paths of quark and gluon, antiquark and gluon, and quark and antiquark correspondingly.

To average the Wilson loop configuration (3) one may use the cluster expansion method [4] with the result

$$\langle \mathcal{W} \rangle_B = \frac{N_c^2 - 1}{2} \exp - \sigma(S_1 + S_2) \quad (4)$$

for large contours, where S_1 and S_2 are the minimal areas inside the contours formed by paths of quark and gluon and antiquark and gluon.

To formulate the Hamiltonian approach one should extract the effective Lagrangian from (2), and reduce the four-dimensional dynamics to the three-dimensional one. Assuming the straight-line approximation for the minimal surfaces, one arrives to the Hamiltonian for the $q\bar{q}g$ system, which for low orbital momenta takes the form

$$H = \frac{m_q^2}{2\mu_1} + \frac{m_{\bar{q}}^2}{2\mu_2} + \frac{\mu_1 + \mu_2 + \mu_3}{2} + \frac{p^2}{2\mu_p} + \frac{Q^2}{2\mu_Q} + \sigma\rho_1 + \sigma\rho_2, \quad (5)$$

where the Jacobi coordinates \vec{r} and $\vec{\rho}$ and conjugated momenta \vec{p} and \vec{Q} are introduced,

$$\mu_p = \frac{\mu_1\mu_2}{\mu_1 + \mu_2}, \quad \mu_Q = \frac{\mu_3(\mu_1 + \mu_2)}{\mu_1 + \mu_2 + \mu_3},$$

and the quantities μ_i are the fields over which one is to integrate in the path integral representation, or, equivalently, to take extremum in μ_i in the Hamiltonian. It appears, however, that one may first find the eigenvalues of the Hamiltonian (5) assuming μ_i to be c -numbers, and then minimize the eigenvalues in μ_i , considering, in such a way, μ_i as constituent masses of quarks and gluon. This procedure works with rather good accuracy for the lowest states.

The physical states are defined to be transverse with respect to the gluon momentum, so that the possible quantum numbers for the ground state hybrids are

$$J^{PC} = 0^{\mp+}, 1^{\mp+}, 2^{\mp+}, 1^{\mp-}. \quad (6)$$

The actual calculations of the mass spectra were carried on with the inclusion of Coulomb force with $\alpha_s = 0.3$ and the values of quark masses were chosen to be $m_q = 0.1GeV, m_s = 0.25GeV, m_c = 1.5GeV$. The absolute mass scale was set by adding the constant term to the Hamiltonian, which was chosen to be twice as in the corresponding $q\bar{q}$ system. The results for the masses of ground state hybrids read:

$$M(q\bar{q}g) = 1.7GeV, \quad M(s\bar{s}g) = 2.0GeV, \quad M(c\bar{c}g) = 4.1GeV. \quad (7)$$

The values (7) appear to be very close to the mass range where the hybrid candidates are believed to be placed [5], and to the values obtained in the flux tube model [6]. The latter has a lot of common with the present approach: both models take into account the transverse motion of the string. The main difference is in quantum numbers: in the present model a perturbative gluon which carries its own quantum numbers is needed to make a string vibrate.

At present several hybrid candidates are under discussion [5], with hybrid assignment suggested not only because of the values of masses, but because of their decay properties: the decay of hybrid into two S -wave mesons is suppressed in the flux tube model. Just the same signature exists for a hybrid with electric constituent gluon [7]. So more sophisticated selection rules involving spin content of the decay products [7] are needed to tell the flux tube from constituent hybrid.

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